PATENT SPECIFICATION

(11) 1 204 261

1 204 261

DRAWINGS ATTACHED

(21) Application No. 2646/68 (22) Filed 17 Jan. 1968
(31) Convention Application No. 3537 (32) Filed 17 Jan. 1967 in
(33) Japan (JA)
(31) Convention Application No. 50042 (32) Filed 4 Aug. 1967 in
(33) Japan (JA)
(31) Convention Application No. 52563 (32) Filed 16 Aug. 1967 in
(33) Japan (JA)
(45) Complete Specification published 3 Sept. 1970
(51) International Classification B 22 f 3/08 7/04 B 44 d 1/08
(52) Index at acceptance

B2E 18Y 191 193 197 19Y 203 207 208 209 20Y 23Y 251 319 321 327 339 348 349 402 403 405 406 40X 40Y 413 41X 41Y 449 44Y 459 469 512 518 529
B5A 1K2A1B 1R102 1R14C1B 1R58 1R64 1S 2G
C7D 8A1 8F 8K 8M 8N 8R 8W 8Y 8Z12 8Z13 8Z3 8Z4 8Z5 8Z8 8Z9 A1 A3
C7F 1G1 2A 2H 2L 2M 2P 2U 2Z2 4A 4F 4G 4K 4N 4X

(54) IMPROVEMENTS IN OR RELATING TO FORMING COHERENT BODIES BY BONDING PARTICLES

(71) We, JAPAX INCORPORATED, a Body Corporate organised under the laws of Japan, of 100, Sakato, Kawasaki, Kanagawa, Japan, do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention is directed to a method of forming coherent bodies by bonding particles together with the aid of impulsive forces.

According to one known method, relatively massive bodies, e.g. metal plates, have been shaped and/or bonded to other similar bodies by impulsive action generated at least in part by an electrical discharge in a fluid. It has now been found that the principles of this method can be applied to bond particles of metal together, to bond particles of metal to particles of another material, and to bond particles of one material to a relatively massive body of another material in that an electrical discharge in a fluid, e.g. a viscous medium such as a liquid or a gas, produces a shock wave which can be transmitted to the particles directly or indirectly (e.g. via a ramp) to compact the particles.

While the fusion of particles of a metallic powder to form a coherent structure is not new, the conventional methods of accomplishing this task have heretobefore involved the provision of sufficient kinetic energy in the form of heat to effect a thermal fusion at the interface of the particles. The disadvantages of these conventional methods are well-known and need not be elucidated here except to note that they require relatively high temperatures and pressures.

There has also been disclosed a method of sintering discrete particles together wherein the high pressures and extreme thermal conditions of conventional sintering methods can be avoided. In this method, electric-spark discharge is employed to provide an impulsive force which is more or less instantaneous in nature and serves to drive the particles into contact with one another at high pressures, while a discharge is propagated amongst the particles to cause bridging between individual particles, an operation which appears to result from the transfer by the discharge of material from one particle to another. This system is highly suitable when a spark discharge can be developed between two electrode surfaces having the particles disposed therebetween; however, the power necessary for the coating of large-surface continuous bodies with the particles is not as readily available, the mass of particles is not materially compacted by the spark discharge and external pressure must be applied to compact the sintered body. It has also been proposed by others, to clad a continuous metallic substrate with another metal layer by spacedly juxtaposing the layer and the substrate over relatively small distances and propagating an explosion along the surface of the layer such that the latter is effectively rolled onto the substrate parallel to the layer. According to this system, a sheet explosive is applied over the full surface of the layer at which bonding is required and

propagation is effected parallel to the explosive layer, the substrate and the coating layer. Such arrangements are not, however, practical for the coating of substrates with pulverulent materials.

It is an object of the present invention to provide an improved method of coating metal substrates with pulverulent materials in such manner as to render the coating layer highly adherent while obviating the disadvantages of earlier coating processes.

According to the present invention there is provided a method of forming a coherent body comprising forming a mass of a powdered material, and compacting said mass by bodily subjecting the mass to the energy of an externally generated shockwave transmitted via a fluid medium thereto and produced by spark discharge in the fluid medium, the energy of said shockwave being sufficient to cause the particles of the powdered material to bond together.

It has been found also that excellent results are obtained with respect to the bonding of particles of a hard-facing material of the type set forth above or alloy steels to metallic substrates and synthetic-resin substrates if the discharge source is spaced from the mass of powder which, in turn, is disposed between the source and the surface of the substrate to be coated. Thus, it is advisable to support a layer of powder upon a rupturable diaphragm such as a frangible foil, film, sleeve or sheet juxtaposed with the surface to be coated. The rupturable diaphragm, supporting the particle layer, separates the discharge chamber from the workpiece chamber. The latter, of course, can be vented to the atmosphere to prevent the development of pressures resisting kinetic movement of the particles into bonding engagement with the workpiece and the venting means preferably includes a sound-damping muffler.

In accordance with this aspect of the invention, it has been found that a significant improvement in the degree with which the particles bond to the substrate can be attained when the particles are located in the discharge compartment although, in accordance with a modification, the particle layer may be carried by the frangible diaphragm along its surface juxtaposed with the workpiece and remote from the discharge chamber. Furthermore, the frangible diaphragm preferably constitutes the counterelectrode for the discharge system and this arrangement has been observed to give excellent results when broader surfaces of a workpiece are to be coated because the particle cloud is then driven against the workpiece with the kinetic energy that, while greater in the region of local discharge, may be considered substantially uniform over the entire cross-section of the cloud for practical purposes. The discharge electrode is a needle spaced from the frangible diaphragm, which can be an aluminum foil or composed of any other suitable metal, the needle extending perpendicularly thereto.

In accordance with this aspect of the invention, it has been found desirable to provide the discharge chamber as a discharge gun whose barrel is trained upon the workpiece and receives at an intermediate location a mass of particles to be propelled thereagainst. In a horizontal position of this barrel, the particles can be introduced substantially continuously between the discharge chamber and the mouth of the barrel while a rapid train of pulses is supplied across the electrodes so that a sequence of discharges results in an intermittent but high-rate propulsion of the particles against the workpiece surface. In vertical positions of the barrel, it has been found most practical and highly advantageous to make use of the foiltype support and counterelectrode set forth above. The needle electrode is best constituted of aluminum although zirconium, magnesium and copper have been found to rank in that order with reference to the kinetic energy transferred to the particles. Correspondingly, the foils should be constituted of these metals in the order stated. While I do not wish to be bound by any theory as to the reasons why the bonding effect and the kinetic-energy characteristics of the metal particles are determined in part by the metal from which the needle electrode and foil are constituted, it will be noted that rupture of the foil, partial vaporization of the electrode material during the discharge and the high velocity of the shock propagation permit any atoms or molecules of the electrode material to act in force-transmitting relationship with the particles to be deposited.

According to another aspect of this invention, the effective kinetic energy of the particles and the strength with which the particles bond to the surface, whether it be to a metallic or a synthetic-resin substrate, can be augmented by providing means for heating the particles to a temperature less than their fusion point prior to their propulsion against the substrate. Such heating means can include the passage of a heating current through the mass of particles in advance of the discharge, the use of external electric heating means or some equivalent source or, most advantageously, the mixing with the particles to be deposited of a substance adapted to react with these particles exothermically. Thus, aluminum oxide can be provided together with a reducing agent (e.g. iron) or magnesium with iron oxide in thermitetype reactants capable of evolving sufficient heat to improve the bonding effectiveness. It has been observed that thermitetype reactants tend to remain in a quiescient state until the generation of a

spark discharge and that the reaction may occur slightly before or concurrently with dispersion of the particles so that they are heated without material interparticle fusion until they accumulate again as a layer upon the surface of the substrate.

Another factor entering into the improved bonding action appears to be the effect of the spark discharge in stripping oxide films from the particles and/or the substrate even though analysis shows no material oxide layer to be present. Practically all metallic particles have an oxide film which resists interparticle bonding as well as particle-to-substrate bonding to such an extent that high temperatures have hitherto been required to effect suitable bonding strength. The discharge between adjoining particles tends to strip such oxide films therefrom and it has now been discovered that an electric discharge in the region of the particles and not necessarily involving them directly may have a similar effect. It will be noted that various methods of initiating the discharge can be employed although two have been found most practical in combination with the foil-and-needle arrangement set forth earlier. In such an arrangement, the needle can either be advanced toward the foil to reduce the discharge gap (whereby an external source of pulses is not required), or the ionization conditions within the discharge compartment may be suddenly modified. This can be done effectively by directing a stream of compressed air into the chamber to stir up a cloud of the conductive particles to be deposited, whereupon a breakdown is produced. The discharge-propagated particles form a layer of considerable uniformity and highly effective surface area. Thus, when tantalum or titanium are deposited upon an aluminum foil, excellent capacitor plates are obtained. When gold or aluminum are formed as films upon a silicon wafer, excellent semiconductive materials are produced. Photoconductive cells can be made readily by deposition of lead sulfide and cadmium sulfide upon suitable substrates.

The detonation source can include a pair of electrode elements adapted to define between them an electric-discharge gap, the pulverulent material being disposed in close proximity to the gap and advantageously surrounding it. The gap can be temporarily bridged by a fusible element which is disintegrated upon discharge of a high-energy pulse across the gap and serves to lengthen the effective time of discharge as a consequence of the delay opening of the gap. As described in patents Nos. 3,232,085 and 3,232,086, shockwave is propagated through the fluid medium between the source and the substrate of a high velocity sufficient to deform a workpiece, but here used to bond particles to a workpiece surface. Notwithstanding earlier teachings regarding the necessity that the propagation of the explosive wave be parallel to the surface, excellent results are obtained when the particles are disposed in the region of the detonation source and the viscosity of the surrounding medium is reduced (e.g. by evacuating the region of the detonation). Powders having a particle size ranging between 0.2 microns and 0.2 mm are suitable for the practice of the present invention while the distance of the source from the substrate varies as a function of the applied energy. When a discharge of 3000 joules is employed, for example, in an atmospheric medium but at a reduced pressure of 10^{-2} mm of mercury, the detonation source should be about 15 mm from the workpiece. It has been found that the shockwave and, therefore, the particles accelerated thereby should attain a minimum velocity of about 10m/sec, although the effectiveness of bonding falls off sharply below 100 m/sec and velocities as high as 10 km/sec are suitable. The particles may be composed of relatively hard metals or metallic substances among which the most preferable are tungsten carbide, titanium carbide, boron carbide, nickel, copper and iron. Almost any suitable substrate may be employed (e.g. steel, nickel, copper and its alloys, synthetic-resins). Nonmetallic particles of diamond, silicon carbide, aluminum nitride, boron nitride, lead sulfide, cadmium sulfide and can also be readily bonded to these substrates. Other useful powders include Al_2O_3, SiO_2, PbO_2 and ZnO, all of which can react with oxidizable metals in exothermic processes as mentioned above.

The shockwave, entraining the particles at high velocity in the direction of the workpiece, may be concentrated in this direction by suitable deflection means (e.g. mechanical reflectors or electromagnetic devices taking advantage of the fact that the particles are magnetically permeable and the detonation wave generally contains ionized or charged particles produced by the detonation). It has been found to be advantageous to provide a high-frequency electric field across the region in which propagation takes place.

It has also been observed that, when the particulate material is to be applied to the substrates by a high-energy-rate deposition apparatus or " gun ", according to the invention, there is frequently a loss of efficiency and control by virtue of the fact that the particulate materials often are dispersed by the shockwave prior to rupture of the foil. Consequently, the particles may be dispersed within the shock-generating chamber and be partly propelled in directions other than that which is intended. To avoid this disadvantage, and to increase the rate at which the shockwave chamber can be supplied with the particulate material and the reproducibility of such supply, there is provided a foil with a

multiplicity of pockets, each enclosing a predetermined quantity of the particulate material, the pockets being successively aligned with the shockwave generator and supplied to the latter in the form of a belt.

The particulate material is pocketed between a pair of metallic foils which thus form a laminate as well as counterelectrodes for juxtaposition with a needle electrode. The apparatus thus may be provided with a barrel portion and a shockwave generator portion, these portions being separable to receive the pocketed foil between them. It is advantageous to employ as the pocketing foil or foils, one or more materials which are intended to be found subsequently upon the coated surface. The foil material may be a substance which is readily bondable both to the particles and to the substrate inasmuch as a substantial portion of this foil is found to be present at the interface between the particles and the substrate. For example, nickel foil is used when tungsten carbide or like hard-facing material is to be bonded to steel. It appears that the nickel acts as a bonding layer between particles of the hard-facing material and of the substrate and derives from the foil originally employed to retain the particles. While loose masses of such particles have been proposed as being retained within a pair of foil layers in respective pockets, it is also conceivable to lightly sinter or adhesively bond respective masses of particles in molded masses which are spaced along a continuous foil; The masses may also be adhesively bonded to this foil. The interparticle bond should, of course, be as little as possible so as to conserve the shockwise energy and utilize the maximum energy for implanting the particles into the substrate.

A contoured cavity or other surface may be coated with particulate materials by juxtaposing with this surface an array of shock tubes or guns, extending transversely to the surface regions confronting them, but oriented so that their mouths define a surface generally parallel to that of the workpiece.

The preheating of the particles appears to play a highly significant role in the degree of bonding to the surface and in the proportion of the material which adheres firmly to the substrate; additionally, it appears that electrically subdivided particles are more readily adherent and penetrate more effectively into the substrate surface as is described in greater detail below.

A particulate mass may also be formed in situ within the barrel of the discharge chamber by thermal destruction of a fusible material, the thermal destruction being effected by electrical disintegration or erosion of the fusible element by hot gases, preferably in a plasma condition. In this aspect, a pair of particle-forming electrodes is located at a location ahead of the discharge electrode and these particle-forming electrodes are heated by electrical resistance or arc-forming techniques to vaporize the metal of at least one of these electrodes and form particles which are totally gaseous in nature or, upon condensation or solidification at the temperature within the discharge chamber, are in a liquid or solid finely subdivided state. In effect, therefore, the particle cloud produced in this manner is a condensate of a particle size substantially smaller than the particles of similar materials made by mechanical techniques. Still another feature of this aspect of the invention resides in heating a fusible wire by arc discharge or resistance heating and generating the impulsive discharge when the heated portion of the fusible wire is only slightly coherent so that the energy of the discharge first disrupts the heated body and breaks it into the particles of liquid or semi-solid material and thereafter entrains or propels these particles against the substrate. In a system of corresponding effectiveness, a plasma gun is provided to inject a particle cloud contained in a hot plasma into the discharge chamber just ahead of the electrode. Such a system represents a vast improvement over prior " flame-plating " processes.

Another feature of the present invention involves the surprising discovery that a minimum repetition rate of the order of 0.5 to 1 cycle per second of the spark discharges in the impulse generator is necessary to provide a satisfactory degree of deposition upon a metallic substrate. Thus it has been found that a surprising increase in the quantity of particles developed per unit power consumption is obtained when the spacing between pulses of the generator decreases from a frequency of 0.5 cycles/second to a level which may be of the order of kilocycle/second. As a practical matter, however, impulses may be triggered at a rate of 10 to 500 cycles/second, depending upon the rate at which particles can be fed to the gun. Thus, optimum deposition is obtained when a pulse frequency (with corresponding interpulse spacing or delay) of 0.5 to 500 cycles/second is used. Of course, the pulse frequency must be less than that at which continuous discharge is generated across the spark electrodes.

The principles described above may also be for the patterning of workpiece surfaces. The term " patterning " as used herein, is intended to refer to the formation of designs, textures, color distributions and imprinting on metallic or other workpieces. For example, detonation type spark-discharge waves may be used to propel synthetic resin particles in a slightly preheated state against paper or synthetic-resin substrates which have been electrostatically charged in accordance with a predetermined pattern to thereby fix the particles to the surface even without the aid of heat. Alternatively, a stencil or mask, may

be disposed between the particle-receiving surface of the workpiece and the impulse generator to form patterns upon the workpiece in accordance with the openings in the mask or stencil. Still other patterning possibilities may make use of the fact that a magazine-like supply of particles is delivered in doses or precisely measured portions to the impulse generator which may make use of particles in the respective dose or measured portion of different colour. Especially when a stencil is differently coloured areas may be formed on the workpiece. The coloured particles may be formed in situ in a pigment-producing reaction from, for example, a metallic rod. Particles of two or more metals oxidized to a predetermined colouration level, can be formed by effecting an arc discharge between the electrode rods ahead of the impulse generator.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings.

Fig. 1 is a vertical cross-sectional view, in diagrammatic form, showing an apparatus for depositing particulate materials upon a workpiece;

Fig. 2 is a diagrammatic sectional view showing a modified apparatus;

Fig. 3 is a view similar to Fig. 1, wherein, however, a high-frequency field is employed concurrently;

Fig. 4 shows a modified circuit arrangement for the system of Fig. 3;

Fig. 5 is a fragmentary elevational view showing still another modification of the detonation source;

Fig. 6 is a view similar to Fig. 5 illustrating the use of a fusible wire within the body of particulate material;

Fig. 7 is a transverse cross-sectional view through yet another modification of the source, provided with reflector means;

FIG. 8 is a diagrammatic elevational view, partly in section, showing a magnetic-deflection arrangement;

FIG. 9 is an illustration of the arrangement of the present invention as used in Example I;

FIG. 10 is an axial cross-sectional view of an apparatus embodying the principles of the present invention in accordance with a modification thereof;

FIG. 11 is an axial cross-sectional view of a vertical-barrel particle-deposition gun somewhat in diagrammatic form;

FIG. 12 is an axial cross-sectional view of another gun arrangement in which the particles are projected downwardly; and

FIG. 13 (sheet 6) is a cross-sectional view through a system in which the particles are bonded together by the impulsive energy.

FIG. 14 (sheet 7) is a diagrammatic cross-sectional view illustrating an apparatus for the coating of surfaces according to the present invention;

FIG. 15 is an axial cross-sectional view of another embodiment of a coating apparatus according to this invention;

FIG. 16 is a view generally similar to FIG. 14 of a system wherein the doses of particles may be formed concurrently with the coating;

FIG. 17 is a diagrammatic elevational view with accompanying circuit diagram of an apparatus for uniformly coating relatively broad flat surfaces according to this invention;

FIG. 18 is an elevational view of a multi-tube array of the type shown in FIG. 17;

FIG. 19 is a view similar to FIG. 18 of another array;

FIG. 20 is an elevational view in diagrammatic form of a system for the coating of a convex surface;

FIG. 21 is a diagram illustrating a further modification of an apparatus for coating convex surfaces of complex configuration;

FIG. 22 is an enlarged detail view, partly in cross-section, of the cooling means for an impact-deposition barrel according to an aspect of this invention;

FIG. 23 is a diagrammatic cross-sectional view of another apparatus for practicing this invention using other cooling means;

FIG. 24 is a graph showing the relationship between barrel temperature and particle adhesion to the barrel;

FIG. 25 is an axial cross-sectional view of a modified system for depositing particles upon a substrate;

FIG. 26 is still another cross-sectional view through a coating apparatus;

FIGS. 26A—26D are graphs illustrating an aspect of the invention;

FIG. 27 is an axial cross-sectional view through a magazine-type deposition device;

FIG. 27A is a section along line A—A of FIG. 27; and

FIG. 28 is a cross-sectional view in diagrammatic form of a system using a plasma torch for supplying the particulate material to the discharge gun.

In FIG. 1 there is shown a housing 10 whose compartments 11 and 12 on opposite sides of a workpiece 13 contain electrode supports 14 and 15, respectively. The supports 14, 15 are horizontally displaceable within respective bearings 16, 17 against the force of restoring spring 18 and carry spark-discharge electrodes 19, 20 via locking screws 21, 22. The electrodes 19 and 20 define a discharge gap 23 between them and are surrounded by a mass 24 of particles to be coated onto the workpiece 13. The latter is disposed below the detonation source constituted by the electrodes. A capacitor 25 is bridged across the electrode holders 14, 15 together with a parametrically energizable capacitor 26, the parametric transformer being constituted by a solenoid coil 27 surrounding

the armature 28 rigid with the electrode holder 15. A full-wave rectifier bridge 29 is connected across the secondary winding of a power transformer 30 supplied with current by the a.c. source 31 and energizes the low-turn portion of the solenoid 27. A servomotor 33 (known per se) is provided to sweep the detonation source along the surfaces of the workpiece 13 perpendicularly to the plane of the drawing.

When alternating current is applied at 31 to transformer 30, the capacitors 25 and 26 are charged via the respective windings of the solenoid 27. When a sufficiently high potential is attained for a breakdown of the gap 23, a spark jumps between the electrodes 19 and 20 and the resulting impulsive force of detonation drives the pulverulent material into the workpiece 23. The discharge of capacitor 25, for example, draws current through the solenoid 27 and effects a lateral oscillation of the assembly against the force of spring 18, capacitor 26 further sustaining the discharge and promoting oscillation while lengthening the duration of the detonation. This oscillation increases the area of the workpiece 13 swept by the detonation wave.

FIG. 2 illustrates a modification wherein the electrode 32, 33, surrounded by the pulverulent material 34 is juxtaposed with a further body 35 in line with the gap. Either the workpiece 36 or this further body 35 can constitute a reflector redirecting the shockwave and making maximum use of the discharge. Similarly, either one of these two elements can be the workpiece upon which the pulverulent material is deposited. A partition 37 (dot-dash lines in FIG. 1) can close the compartment 38 in the housing and enable it to be evacuated for low-pressure deposition. Additionally, nonoxidizing gases (e.g. nitrogen) can be employed as the medium within the compartment.

In the system of FIG. 3, the vessel 40 is closed by a seal 41 and a cover 42 while a suction pump 43 serves to reduce the pressure within the vessel. The vessel contains a pair of spaced-apart plates 44, 45, constituting the workpiece and disposed on opposite sides of a deonation source constituted by a pair of electrodes 46, 47 urged inwardly by respective springs 48. The mass of particles is here constituted as a relatively narrow tube 49 of powder through the interior of which a discharge can be initiated upon closure of switch 50. Here again the discharge source extends parallel to the surfaces of the workpiece 44, 45 to be coated so that the shockwave is generally transverse to these surfaces. A direct-current bridge 51 charges the capacitor 52 via a surge-suppressing inductance 53 upon energization by the power transformer 54 and the a.c. source 55. A high-frequency direct-current source 56 connected with the plates 44, 45 facilitates the deposition of the powder and improves the structure of the deposit. The high-frequency signal can range between 1 kc/sec to 10 mc/sec.

In FIG. 4, a similar arrangement is shown, except that the a.c. or high-frequency generator 56 is provided by a pair of resonant networks 57 formed on opposite sides of the inductance center tap and connected with the plates 44, 45. Since these electrodes are now at the same polarity, the high-frequency field produced upon discharge across the gap is applied between the body of powder and the plates. The shockwaves of FIGS. 3 and 4 can be augmented by disposing a fusible wire 58 parallel to the powder rod 59 between the electrodes 60, 61 (FIG. 5); the system is otherwise identical with that of FIG. 3. The ganged switches 62, 63 fulfill the function of switch 50 of FIG. 3 and are adapted to discharge the capacitor 52 joined through the spark gap and the fusible wire which is disposed on the side of the rod 59 opposite the workpiece. The shockwaves from fusible wire and arc discharge thus supplement one another in driving the powder across the gap. This system is an improvement over the mere spark discharge with respect to the quantity of powder affixed to the substrate per unit of powder consumed.

A still more efficient system results when the fusible wire is surrounded by the mass of particles as shown in FIG. 6. Here, the fusible wire 70 is surrounded by a tubular mass 71 of the particles to be bonded to the substrate 72. A capacitor 73 can be discharged through the wire 70 to disintegrate it when switch 74 is closed, a battery 75 being provided to charge the capacitor 73. Again means can be provided for oscillating the detonation source with respect to the workpiece or otherwise displacing the source and workpiece relatively to obtain maximum powder coverage. The system of FIG. 6, can, moreover, be provided with a downwardly concave (e.g. parabolic) reflector 76 with the rod 70 disposed at the focus. An excellent distribution of the powder is obtained in such a system while the depositing efficiency is improved (FIG. 7). When the mechanical deflection is replaced by an electromagnetic deflection of the shockwave, the magnetic means 77 (FIG. 8) is oriented so that its field is applied transversely to the detonation source 78 and the workpiece 79 but in the plane of the detonation source. Highly suitable results are obtained when the detonation source includes a fusible wire 80 connected in series with the electromagnet 77 across the capacitor 81. A switch 82 permits discharge of the capacitor through the series arrangement and allows charging of the capacitor by the battery 83 when the switch is open. In this case, no difficulties are encountered in synchronizing the pulsed magnetic field with the discharge.

It should be noted that the pulverulent mass

can be held in the region of the discharge or fusible wire by a loose-bonding agent (e.g. a synthetic resin) admixed with the powder, or by a retaining tube or structure of synthetic resin or paper with the latter method being preferred. It has been found that the presence of an extraneous substance like the resin tube does not affect deposition which takes place whether such a tube is provided or the particles are held in place by some other means. Note that the powder in these systems will completely fill the gap between the electrodes.

EXAMPLE I

In an arrangement similar to that of FIG. 9, tungsten-carbide powder 90 having a particle size of about 0.1 mm, was disposed in a polyethylene tube 91 having a wall thickness of 0.2 mm and an inside diameter of about 25 mm. A fusible copper wire 93 was passed axially through the tube and had a diameter of about 0.12 mm. The wire, tube and workpiece 94 had a length of about 10 mm, the workpiece being composed of S55C carbon steel having a carbon content of 0.55% by weight. The detonation assembly was disposed at a distance 95 of 15 mm from the surface of the workpiece in a chamber such as that shown in FIG. 3 and was maintained at a reduced pressure of 10^{-2} mm of mercury. After an electric current was passed through the wire sufficient to melt it and cause a discharge with an energy of 3000 joules, the deposit 96 upon the surface of the workpiece was measured. The deposit was found to have a thickness of 0.06 mm and to cover a width of the workpiece (i.e. transverse to the major dimension of the wire) of about 50 mm, the central 25 mm of which was a continuous zone while the outer 12.5 mm on each side was discontinuous. The roughness of the surface at the central portion was found to be 3 microns (H_{max}). The discharge pulse had a duration of about 85 microseconds. Two hardness $H_v = 2100$ (on the Vickers scale). When the arrangement of FIG. 8 was employed using a magnet having 4—5 turns with a current ranging between 1000 and 5000 amperes, the layer of tungsten carbide was found to have the same hardness but a thickness of 0.1 mm and a roughness of 3—4 microns H_{max} in both cases; the velocity of the particles range between 100 m/sec and 5 km/sec.

In the system of FIG. 10, the discharge chamber is formed as a barrel 100 whose mouth 101 is trained at the surface 102 of a substrate 103 which can be either conductive or nonconductive, as described earlier. A gap 104 is provided around the zone of the surface 102 surrounded by the barrel 100 to prevent pressure increases therewithin from reducing the kinetic energy of the particles projected against the surface 103. At the other end of the barrel 100, an insulating block 113 receives a needletype electrode 112 which can be threaded into the barrel 100 axially to a variable distance t from the region at which a hopper 114 feeds the pulverulent material 105 into the barrel transversely. The hopper 114 is provided with a feeding or metering mechanism 115 whose motor 116 is driven intermittently by a timer 117 which also controls a switch 109 in the supply circuit for the "gun" The supply circuit 106 comprises a direct-current source (shown as a battery 108) across which is bridged a capacitor 107 in series with a charging resistor 110. The distance t is adjusted in this embodiment until closure of switch 109 will result in a discharge behind the mass of particles 105 whose presence modifies the breakdown voltage which must be applied between the needle 112 and the barrel 100 across which the pulsing source 106 is connected. When larger quantities of conductive powder 105 are supplied in the region of needle 112, the breakdown voltage is reduced and rapid pulses can be supplied so that a train of discharges at a repetition frequency determined by the timer 117 and synchronized with the particle feed means can drive these particles against the surface 102. In general, the discharge takes place rearwardly of the particle mass 105 and among these particles to partially ionize them, strip their oxide films and effect direct transfer of kinetic energy to the particles. It will also be understood that the timer means need not be used inasmuch as closure of switch 109 will apply a given potential between the needle 112 and the barrel 100 and the firing of the discharge can be initiated either by advancing the needle 112 or by introducing a sufficiently large mass of the particles 105.

In the modification of FIG. 11, the barrel 200, trained upon the substrate 203 with a clearance 204 to prevent excess static pressure buildup in the barrel, is provided with feed means including a supply roll 219 for a foil 220 of a conductive material. The chamber 221 is formed at least in part by a barrel portion 222 electrically insulated from a needle 212 which can be advanced by a motor 223 or hydraulic means as illustrated in greater detail in FIG. 12. A pulse source such as that illustrated at 106 in FIG. 10 can be connected across the needle 212 and a basket-shaped counterelectrode 224 just behind the foil 220. Thus the foil 220 constitutes a frangible diaphragm sealing the open end of chamber 221 and carrying a mass of, for example, nonconductive or partially nonconductive particles 205. Upon discharge across the gap between the needle 212 and the counterelectrode 224, the shockwave destroys the diaphragm 220 and propagates the particles 205 against the surface 203 to form a coherent layer 225 thereon. It will be understood that the counterelectrode 224 can here be omitted and the

corresponding terminal of the pulse source 206 connected to the foil 220 so that the latter may serve as the counterelectrode as illustrated in Fig. 12.

EXAMPLE II

Using an apparatus as in Fig. 11, the foil 220 was a nickel-and-metal foil having a thickness of approximately 0.006 mm. The particle mass was constituted by equal proportions of 300-Mesh tungsten carbide and 600-Mesh synthetic diamond. 5 grams of the particle mixture were placed upon the foil and a discharge with an energy of 8000 joules was applied at the needle 212. The workpiece was a 0.55% by weight carbon steel (S55C) and the coated surface was a distance of 12 mm from the foil. About 4 grams of the particles were found to be strongly adherent to the workpiece. Corresponding results were obtained when the particles were composed of silicon carbide, aluminum nitride, boron nitride and titanium carbide. When the workpiece was replaced by an aluminum foil it was found that deposition of titanium and tantalum particles was readily carried out with the same discharge energy and device.

In a modification of the system of Example II, the particles specified therein were mixed with a binder to form a disk which was placed upon the foil 220. Binders tested for this purpose included cellulose propionate, para-oxybenzaldehyde, ally alcohol resin and hard rubber. In all cases the binder was present in an amount just sufficient to hold the mass together and it was found that the shock wave resulted in a penetration of the particles into the body as individual and discrete units in spite of their bound state prior to the discharge. Penetration of the particles was improved by incorporating atoichiometric equivalents of chromic oxide and of reducing binders of the character described.

In the system of Fig. 12, the barrel 300 extends into a coating chamber 330 lined with a sound-damping elestomeric material 331 such as foam rubber. The chamber 330 is vented through a muffler 332 and is provided with a cross-feed support 333 for the workpiece 303. The cross-feed includes spindles 334 and 335 for longitudinal and transverse displacement of the workpiece 303. The upper part of the barrel 322 is separated from the lower portion 300 by insulating spacers 336 upon which the foil 320 is mounted. The foil carries the mass 305 of particles and here disposed within the chamber 321 in which the spark is generated. The needle 312 passes through an insulating bushing 313 and is connected with a supply network 306 of the type illustrated in Fig. 10. The firing control of the system is here regulated by a hydraulic motor 323 whose piston 327 is connected with the needle 312 for hydraulically advancing same. A distributing valve 338 in circuit with a hydraulic pump 339 and a reservoir 340 provides the necessary regulation of a hydraulic device 323. When the electrode needle 312 approaches the foil 320 sufficiently a discharge results in rupture of the foil diaphragm and the propagation of the particles against the workpiece 303. The discharge can also be initiated by the operation of a compressed-air source 341 designed to blow a stream of air into the chamber 321 and stir the particles therein to effect a breakdown between the electrode and the foil.

In FIG. 13 the device 400 comprises a fluid receptacle 401 which itself constitutes the piston of a hydraulic cylinder 457. Inlet and outlet tubes 420 and 419 circulate the liquid medium 404 within vessel 401 via a filter. A piston 439 is slidably displaceable within vessel 401 and is provided with an insulating lining 439a. Piston 439 carries a deposit 408 of electrode material and thus constitutes one of the electrodes forming the spark gap 405, the other electrode being a rod or wire 415 adapted to be fed into vessel 401 by rollers 413 in response to an alteration in the size of the spark gap. A vibratile bar 439'', whose resonant frequency is approximately equal to the resonant frequency of the discharge across gap 405, connects piston 439 with a plate 439' for compression of a conductive powder 440 retained within the cavity 437 of an electrically insulating sleeve 437' which is reinforced by ribs 455 and mounted upon the metal plate 456. The two-position valve 458 is connected in series with the hydraulic cylinder 457 and is supplied by a low-pressure conduit 459 and a high-pressure conduit 460, valve 458 being operated by a control circuit 462 in response to the voltage drop across the mass of particles 440; a battery 461, in series with the control circuit 462, provides the necessary current for circuit 462. The discharge energy is supplied by a capacitor 441 connected between plate 456 and electrode 415, capacitor 441 being bridged by a battery 443 in circuit with an inductance 444 and a resistance 444'. Vessel 401 is provided with an annular recess 452, normally blocked by piston 439, which communicates with a high-pressure accumulator 453.

When conductive particles are employed, capacitor 441 discharges to develop simultaneous sparks at gap 405 and through the particle mass, thereby forming conductive bridges among the particles. The shock wave within vessel 401 rebounds against the piston 439 so that the force of this piston compresses the conductive powder at the conclusion of the electrical discharge. Simultaneously, control 462 senses the decreased voltage drop across the mass of particles and energizes valve 458 to cut off the low-pressure fluid supply to cylinder 457, which formerly displaced vessel 401 to follow the shrinkage of the particle mass, and cut in the high-

pressure conduit. The conductive powder, now sintered into a porous mass but still in a plastic state, is thus subjected to the additive pressure of source 460 and the pressure wave within vessel 401. When nonconductive particles are used, capacitor 441 is connected to the piston 439 as indicated by the dot-dash conductor 463 whereupon the pressure of the discharge at gap 405 is applied to the particles without initial formation of bridges across them by electrical discharge.

EXAMPLE III

A mass of polytetrafluoroethylene particles of 200 Mesh are disposed in a nonconductive sleeve having a diameter of 15 mm and a length of 2 cm. Light pressure was applied at hydraulic cylinder 457 to compress the particle (approximately 1 kg/cm^2) while a discharge in silicone oil within vessel 401 was created. Electrodes composed of an aluminum-copper alloy were used while the single discharge pulse had a duration of 150 microseconds and an energy of 1500 joules. The resulting coherent body had all of the characteristics of a body molded at elevated temperatures although the powder was held at room temperature for the duration of the process.

EXAMPLE IV

The procedure of Example III was followed, except that nickel particles and a spark energy of 5000 joules was used between plate 456 and electrode 415. The pressure applied by cylinder 457 to the particles was 1 kg/cm^2, this pressure being followed upon reduction of the voltage drop across the mass of particles to a value of 500 kg/cm^2, the discharge terminating concurrently with the increase in pressure. The resulting body had a density of greater than 90% of that of the solid mass.

In Fig. 14 the basic apparatus for the high-energy-rate coating of a workpiece 510 comprises a shock tube or gun 511 whose barrel 512 extends into a coating chamber 513 of a housing 514, the coating chamber 513 being lined with a sound-damping elastomeric material 515 such as foam rubber. The chamber 513 is vented through a muffler 516 of the automotive-vehicle or internal-combustion engine type for limiting the intensity of the sound wave transmitted to the atmosphere. Chamber 513 is, moreover, provided with a cross-feed carriage 517 for the workpiece 510, designed to position the workpiece 510 selectively in the path of the particles emerging from the barrel 512. The crossfeed 517 includes spindles 518 and 519 for the longitudinal and transverse displacement of the carriage 517 and the workpiece 510 from locations outside the chamber 514. The upper part of the barrel 512 is separable at the insulating seat 521 of the lower barrel portion 512b. The foil 522 carrying the particulate material 523 is disposed within and partly defines, the spark chamber 524 in which the shockwave is generated. For this purpose a needle electrode 525 passes through an insulating bushing 526 and is connected with a pulse-generating electric-current supply network as previously described. The firing control of the system may be regulated by a hydraulic motor 527 (i.e. a piston-and-cylinder arrangement) whose piston 528 is connected with the electrode needle 525 for hydraulically advancing same toward the foil. A distributing valve 529 in a fluid circuit with the pump 530 and a reservoir 531 provide the necessary regulation of the position of the motor 527. Upon the application of a static voltage across the foil 522 and the needle 525, the latter can be advanced until the gap is so narrow that the potential suffices to break down the gap and a spark discharge bridges same. The discharge results in rupture of the foil diaphragm 522 and the propagation of the particles 523 against the workpiece 510. The discharge can also be initiated by a compreseed-air source 532 designed to blow a high-velocity stream of air-entrained particles into the chamber 524 to effect the breakdown between the electrode 525 and the foil 522 without advance of the needle electrode.

The energizing circuit 533 includes a discharge capacitor 534 connected between the electrode 525 and the housing portion 512a which makes electrical contact with the foil 522. The capacitor 534 is charged through a resistor 535 via a battery 536 and may be discharged across the gap via a switch 537. The latter may represent any electronic breakdown device (e.g. thyratron or solid state controlled rectifier) or other switching means capable of sustaining the capacitor potential and current surge. When the hydraulic motor 527 is inactivated and air is not blown into the chamber 524 to initiate discharge, the spark may be produced on closure of this switch 537.

According to an important feature of this invention, the separable barrel 512 has its lower portion 512b integrally formed or affixed to the housing 514 while the upper portion 512a is shiftable in the direction of arrow 538 alternately toward and away from the lower barrel portion 512b. In its lower position, the upper barrel portion 512a clamps the foil 522 against the bottom barrel portion so that the upper chamber 524 is hermetically sealed and substantially all of the shockwave energy in this chamber is transmitted axially to the frangible diaphragm 522. The latter consists of a generally flat upper layer 522a and a pocketed lower layer 522b in which longitudinally spaced pouches or pockets 522c are formed. When the pockets 522c are filled with a pulverulent material 523 to be

deposited, the foils are brought together and may be thermally fused (e.g. by welding) or may have their longitudinal edges rolled together to fully retain the respective doses of the particulate material. In this embodiment, the upper layer 522a is shown to be concave toward the discharge needle 525 and convex toward the workpiece 510, although of a radius of curvature substantially greater than that of the pocket 522c. The convexity described above appears to promote sufficient transfer of shockwave energy to the particulate material within the pouch. The foil 522 is carried upon a supply roll 53 and can be intermittently advanced into the barrel 512 when the upper barrel 512a is raised by a sprocket 540 whose motor 541 is operated for predetermined intervals by a timer 542. Thus, when the upper barrel portion 512a is raised, the motor 541 and sprocket 540 advance a predetermined length of the foil 522 into the barrel and shift any remnant of the ruptured pocket of the foil out of the system. On the discharge side of the system, the upper barrel portion 512a is provided with a blade 543 which severs the damaged portion of the foil from that remaining. The vertical movement of the upper barrel portion 512a is removed, and a workpiece 510 mounted upon the carriage 517 and positioned in axial alignment with the fixed lower barrel portion 512b via the spindles 518 and 519. An initial length of foil 522, from the supply roll 539, is placed on the lower barrel portion 512b with its convex pocket side turned downward. The upper barrel portion 512a is thereupon replaced and the source 533 is reconnected. Timer 542 can thus close switch 537, while the upper barrel portion 512a is clamped tightly against the foil 522 and produces a spark discharge between the needle 525 and the upper foil layer 522a. The resulting impulsive wave ruptures, in short order, the upper and lower layers 522a and 522c, while propelling the particulate material 523 at high velocity and high kinetic energy against the surface of the body 510 to be coated. Thereafter, timer 542 deenergizes the electrode 525 and activates the valve 546 to raise the upper barrel portion 527 and cause the sprocket 540 to advance the foil by a corresponding length to receive a successive filled pocket of the foil. It will be understood that, instead of, or in addition to, the switch 537, the motor 527 or the valve 529 for the air jet may be activated to initiate the breakdown.

In the system of FIG. 15, the barrel 612, trained upon the substrate 610 with a clearance 650 to prevent excess static-pressure buildup in the barrel, is provided with feed means including a supply roll 639 for a foil 622 of a conductive or non-conductive material. Pockets 623 are formed in the foil as described with respect to FIG. 14 with longitudinal equispacing. The discharge chamber 624 is formed, at least in part, by a barrel portion 612a which can be advanced by a hydraulic motor or an electric motor as represented at 627. Here, the pockets 623 can rest upon a basket-shaped counterelectrode 651 just behind the foil 622 and contacting the latter.

When a current source 633 of the type shown in FIG. 12, for example, is connected across the needle electrode 625, which is shiftable in its sleeve 626, closure of switch 637 will apply a current surge across the gap and effect spark discharge between the needle electrode 626 and the basket electrode 651. Switch 637 also is controlled by a timer 642 which operated a valve 646 of a hydraulic cylinder 644. The piston of this cylinder is connected to the upper barrel portion 612a so that this member can be raised and lowered to release and clamp the foil sections 622. Motor 627 is likewise operated at a cadence determined by the timer 642. In this system, a sprocket 640 and drive 641, likewise controlled by timer 642, advance the foil 622, while a takeup roll 621′ collects the ruptured portions of the foil for salvage, if desired. The foils preferably are of a thickness no greater than 0.01 and 0.02 mm.

Example V

Using an apparatus of the type illustrated in FIG. 15, a pocketed foil 622 was formed from a pair of foil layers having a thickness of about 0.006 mm, with the pocket sufficient to enclose 5 grams of a particle mixture per pocket (see FIG. 16). The mixture was made of equal proportions, by weight, of 300 mesh tungsten carbide and 600 mesh synthetic diamond. The gun 612 was held stationary, while a carbon-steel band 610 was moved above the barrel, the workpiece being composed of carbon steel (0.55% by weight carbon) of the designation S55C. The surface to be coated was located at a distance of 12 mm from the foil. Discharge energies of about 8000 joules per pocket were applied and the foil advanced at an intermittent rate identical to the intermittent rate of advance of the workpiece. The coated surface was found to consist of approximately 80% by weight of all of the particles employed and to be a highly layer. Corresponding results were obtained when the particles were composed of silicon carbide, aluminum nitrate, boron nitrate and titanium carbide. When the workpiece was an aluminum foil, it was found that titanium and tantalum particles could be readily applied to the surface of this foil with the same discharge energy and device. There was no need for any binder in the particle mass and the coating was found to be more uniform and of greater strength than that produced when the particles were merely placed upon the foil and not encapsulated therein. A somewhat greater penetration of the par-

ticles was observed when stoichiometrically equivalent quantities of chromic oxide (oxidant) particles and cellulose particles (reducing agent) were incorporated in the mass within each pocket in an amount up to 10% by weight. It appears that the exothermic chemical reaction between the chromic oxide and the cellulose generated sufficient heat to increase the surface energy of the particles and the degree to which they are bonded to the substrate.

FIG. 16 shows a modified system for the high-rate coating of a substrate 710. In this system, the barrel or tube 712 is generally cylindrical and is formed with a seat 712′ at its upper end at which a frustoconical inner bore 712″ terminates. The barrel 712 is provided with an exhaust muffler 716 of the type illustrated and described with respect to FIG. 14 and advantageously consisting of a tube 716′ filled with a packing 716″ of stainless steel wool or other sound-dampening material. An upper member 724 forms a shock-wave generator and is provided with a needle electrode 725 in an electrically insulated ceramic sleeve 726. The needle electrode 725 is threaded at its upper extremity 725′ and engages a nut 725″ whose toothed periphery meshes with a pinion 727′ of an electric motor 727. The housing 724 and motor 727 are connected together and are shifted in the direction of arrow 738 by a hydraulic cylinder 744. The latter is operated by a valve 736 and receives hydraulic fluid from a pump 730 and a reservoir 731. A timer 742 is provided to operate the valve 746 and lift the barrel 724 from the seat 712′ against which it clamps the foil 722. Timer 742 also is coupled with the sprocket 740, representing the means for advancing the foil 722 intermittently to dispose the pockets 722c in the barrel. The foil 722 may be paid off a supply roll or can be formed concurrently by an encapsulating device 760. This apparatus can, of course, be employed independently of a coating apparatus to prepare the foil for coiling and subsequent use. The system basically comprises a pair of supply rolls 761a and 761b from which nickel, aluminum or other metal foil having a thickness ranging between substantially 0.005 and 0.02 mm and a width slightly in excess of that of the seat 12′ of the apparatus in which the pocketing band is to be used, the foil layers passing between forming rolls 762a, 762a′ and 762b, 762b′, respectively, in which pockets 763a and 763b are respectively formed in the foils 722a and 722b to register and open toward one another. When the apparatus 760 is to be employed for the production of pocketed coils of the type illustrated in FIGS. 14 and 5, only a single set of forming rollers is necessary and the rollers 762b and 762b′ may be dispensed with.

A feed means 764 with any conventional metering device deposits the particulate material in the pockets thus formed as the foils are brought together and encapsulates the masses via a pair of sealing rollers 765. The sealing rollers 765 may be heated to weld the foils together about the pocket or may merely apply sufficient pressure to laminate them together. It is also possible to use a crimping arrangement at these rollers to fold the edge portions of one foil around the other and thereby encapsulate the particulate material. The metering device 764 and the rollers 762a are operated in the cadence of the foil-advancing means 740 and the barrel 724 by the timer 742. Otherwise, the apparatus operates in the manner previously described with reference to FIG. 14.

FIGS. 17 through 21 illustrate various modifications and arrangements of the spark-activated coating gun of the present invention. In FIG. 17, for example, three guns of the general type illustrated in FIGS. 14 through 16, supplied with foil-encapsulated pockets of particulate material from respective supply rolls and energized in succession, are mounted upon a carriage 870 which may be shifted by a spindle 871 parallel to the workpiece surface 872 in the direction of arrow 873. All of these deposition guns or tubes 874 have similar spark chambers and, when the surface 872 is flat, have their mouths lying along a plane P parallel to the receiving surface of the substrate. The means for energizing the coating gun 874 can include a circuit such as that illustrated at 875. This circuit, whose terminale 876 are supplied with direct currents, include a respective capacitors 877a, 877b and 877c energized respectively via chokes 878a, 878b and 878c—and changing resistors 879a, 879b and 879c. The parameters of this network can be such that the left-hand tube 874 (FIG. 17) is energized an instant prior to the energization of the intermediate tube which, in turn, is energized shortly in advance of the right-hand tube 874 as the workpiece 872 is shifted to the left. In this manner, it is possible to move the workpiece with considerable rapidity and apply a relatively thick coating in short order. FIGS. 18 and 19 show several modifications of the orientation of tubes 874. In the system of FIG. 18, the tubes 874′ are aligned in a common vertical plane and thus may extend over the full width of a body such as that diagrammatically illustrated at 872′. In the system of FIG. 19, the shock-tubes 874″ are arranged at the vertices of a triangle and may serve to coat a narrower workpiece 872″. When, however, the workpiece 882 has a relatively complicated contoured surface 882a to be coated with the particulate material, it is most desirable to employ a number of spark-operated deposition guns 884, 884a, 884b and 884c energized by a circuit such as that shown in FIG. 17, and disposed so that

the mouths of these guns lie along an imaginary surface S which is generally parallel and complementary to the surface 882a (FIG. 201). In the modification of FIG. 21, the contoured surface 892a of the workpiece 892 has a positive curvature for the most part, i.e. is convex, the deposition guns 894 being disposed along axes perpendicular to tangents to the surface and thus are perpendicular to these surfaces as well. The guns are spaced as closely together as possible with the illustrated spacing being somewhat exaggerated. Moreover, the mouths of the guns are at identical distances from the confronting surface portions so that they lie generally along an imaginary complementary surface S'. When more than three guns are employed, the energization circuit can include a delay line for firing the guns in any desired sequence or rate at each cycle. Furthermore, while a timer means has been described in connection with FIGS. 14 through 16 and is of course employed in the circuit of each of the guns of FIGS. 17 through 21, it will be understood that such timer means can be triggered by a previous discharge in the shock-wave chamber with a predetermined delay time controlled by the charging of the condensers to their respective capacities.

According to another aspect of this invention, the impact deposition barrel is provided with cooling means to promote the transfer of powdered materials to the substrate and minimize particle adhesion to the barrel. Thus, in FIG. 24, there is plotted the temperature of the barrel along the abscissa in degrees centigrade while the percent particle adhesion to the internal surface of the barrel is plotted along the ordinate. From this relationship it will be apparent that particle adhesion remains relatively low at temperatures up to about 60°C but lies sharply between 70° and 80°C., prior to levelling off at relatively high values at still more elevated temperatures. Since particle adhesion to the internal surface of the barrel is inversely proportional to the number of particles delivered to the surface to be treated and to the period of time for which the device can be used effectively without cleaning, it will be evident that operation of the system at lower temperatures produces considerable advantages and promotes efficient operation especially when repeated discharges are to be produced. Thus it is advantageous to provide cooling means along the barrel for promoting the dissipation of heat therefrom. While this cooling means can include a heat sink in contact with the metallic barrel, i.e. of relatively large heat capacity and high thermal conductivity, or a radiator surface making use of convection currents to effect fluid-solid heat transfer, it is preferable to provide a forced fluid transfer of heat since the amount of heat energy generated by the high-energy-rate deposition apparatus requires relatively high heat transfer efficiency and capability.

FIG. 22 shows a system in which the barrel 1004 of a deposition device of the type illustrated in FIGS. 15—21, is provided with radial fins 1004a around which a fan 1004b displaces a forced stream of air. Any air displacement means can be used for this purpose although the fan 1004b is here shown to have a propeller-type blade 1004c. It is advantageous to confine the cooling fluid in a duct 1004d which encloses the finned region of the barrel 1004 and prevents the high-velocity cooling-air stream from inconveniencing the particle deposition system of this barrel or any adjoining barrels (see FIGS. 17—21).

A modified arrangement with the same purpose is illustrated in FIG. 23 in which the barrel 1114 of a thermally conductive material is in contact with a cooling coil 1114a whose inlet and outlet 1114b and 1114c, respectively, are connected in a fluid-circulation system of any convenient type. The foil 1122, into which the particles are pocketed, may be passed through the system via the displacement means 1139', while the central electrode 1125 effectuates discharge between the foil and itself. The pulse-supplying source 1133 includes a pair of roller contacts 1133' engaging the foil 1122 downstream of the supply coil 1139. The source comprises a battery 1136 which charges the capacitor through a resistor 1135 while the switch 1137, upon closure, applies the impulsive discharge to the electrode. The cooling means of FIGS. 22 and 23 are dimensioned to maintain the barrel temperature below 80°C and preferably below 60°C.

FIG. 25 shows a system wherein the particulate material is prepared from at least one continuous fusible element with the aid of arc discharge or plasma and then is subjected to propulsion by the shock wave of a spark impulse generator. This system is particularly satisfactory because it permits high repetition rates to be attained. The barrel 1600 of FIG. 25 opens in the direction of the particle-receiving surface 1602 of the workpiece 1603 and embodies a pair of arc-discharge electrodes 1615 which are connected in series with a choke 1615a and an a.c. source 1615b to sustain a continuous arc discharge between these electrodes. The electrodes may consist of vaporizable wire and may be electrically decomposed so that vapors of the fusible material of the electrode wire, upon condensation, form a particle mass 1605. The particles are driven against the surface 1602 by a spark discharge from a needle electrode 1612, which may be advanced by a motor 1612a energized by a pulse source 606 whose battery 1608 is connected in circuit with a charging resistor 1610 and a discharging capacitor 1607. A switch 1609 is triggerable

as described earlier to operate the impulse generator.

Example VI

Using the apparatus so far described in connection with FIG. 25, one of the arc electrodes 1615 was composed of a sintered material (85% by weight tungsten carbide, 5% by weight iron and 10% by weight nickel) while the other arc electrode 1615 was pure nickel. Each electrode has a diameter of 5 mm and a length of 150 mm. A d.c. arc discharge at 25 volts and 40 amperes was passed across these electrodes to effect fusion of them. Using the system 1606, 1612 of FIG. 25, a spark discharge was triggered at a location 40 mm behind the gap between the electrode 1615, the spark discharge having 6000 joules energy and a pulse width of 110 microseconds. The workpiece 1603 was a sheet of S55C carbon steel and was located 30 mm away from the mouth of the barrel 1600. It was found that the discharge was sufficient to disrupt the fused portion of the electrode wires 1615 and propel particles thereof in the direction of the workpiece 1603, the single discharge forming a firm coating with a thickness of about 40 microns upon the workpiece. The surface, after receiving the coating, had a hardness of 1200—1500H_v.

Example VII

Following the method described in Example VI, intermittent spark discharges are used with a pulse width of 2.1 microseconds, three such sparks being produced with each spark having an energy of about 2000 joules. Instead of continuous spark discharge between the electrodes 1615, an intermittent discharge was provided in synchronization with the sparks. The resulting layer upon the workpiece 1603 had a thickness of 100 microns and the hardness specified in Example I. In both cases, the wear resistance of the surface was increased from 8 to 10 times.

It will also be understood that the same principle applies if a fusible wire is provided aside from the arc electrodes 1615. Thus, the wire 1615c may be continuously fed from a supply reel 1615d between the erosion electrodes 1615 which are of a refractory metal and do not materially erode during the discharge. Wire 1615c, however, is readily fused at the temperature of the arc between the electrodes 1615. Moreover, the electrodes 1615c is employed in conjunction with a plasma torch 1615c whose high temperature jet suffices to erode the wire 1615 to form the particles 1605.

FIG. 26 shows still another system in accordance with the present invention, this system comprising a barrel 1700 directed toward the workpiece 1703 and composed of an electrically and thermally insulating material in which an annular electrode 1724 is embedded. Electrode 1724 co-operates with an adjustable electrode 1712 as previously described to produce a discharge behind a powder cloud 1705 formed by air injection of powder through the nozzle 1715. A mixing chamber 1715a is represented in diagrammatic form while the control trigger or timer 1717 is shown at 716 to regulate both the switch 1709 and the proportioning of powder and air. The discharge source 1706 here includes a battery 1708, a resistor 1710 and a discharge capacitor 1707.

Example VIII

Using the apparatus of FIG. 26, tests were made with various particulate materials to ascertain the relationship of deposition quantity firmly bonded to the S55C carbon steel workpiece. FIGS. 26A—26D, in which the ordinate shows the quantity of material deposited (in milligrams) and the abscissa, plotted in logarithmic scale, represents the repetition rate in cycles per second. FIG. 26A shows a reposition of tungsten carbide powder after ten discharges, each with 0.1 g of powder and 300 joules spark energy. The graph shows a sharp rise in the deposition quantity in the range of 0.5 to 1 cycle/second. FIG. 26B similarly makes use of aluminum oxide powder with energy of 5000 joules-per-discharge, the same marked increase in deposition quantity being revealed. In FIG. 26C the results obtained with Stellite powder at 1800 joules energy are shown while the conditions with tungsten powder at 3000 joules discharge energy are shown in FIG. 26D. While, with tungsten powder, the rate of increase of the deposition quantity with increasing repetition rate is less than that obtained with the other powders described, a substantial increase nevertheless is seen to take place at the critical region of 0.5—1 cycle/second.

FIGS. 27 and 27A illustrates a system for the repeated powder deposition upon a surface 1802 of a workpiece 1803. In this case, the barrel 1800 of the gun is provided with an opening 1800a through which a rotary disk 1820, composed of metal foil and carrying individual doses 1805 of particles of different color, is rotated on a table 1820a by a motor 1820b. The foil 1820 is electrically conductive and forms a counterelectrode for the main discharge electrode 1812 which can be advanced and retracted by a motor 1812a to trigger the spark discharge. The discharge source is a capacitor 1807 charged through a battery 1808 and a choke 1810. In this system, the foil at each of the particle masses 1805 is disrupted by the discharge and the particles propelled against the workpieces 1803. In addition, however, a stencil 1820c is rotated synchronously with the magayine 1820 so that each color forms its own pattern on the surface 1802.

In the embodiment shown in FIG. 28, the barrel 1900 faces the workpiece 1903 and is composed of a thermally insulating and electrically nonconductive material. The powder is here introduced in a plasma cloud 1905 ahead of the discharge electrode 1912 which is axially shiftable in the barrel 1900 and may receive electrical impulses from a capacitor 1907 charged in the manner previously described, the spark discharge being triggered by a switch 1909 operated by a timer (FIG. 10). The capacitor 1907 may be charged by a d.c. source in the usual manner (FIG. 10). In this case, the powder-containing plasma cloud 1905 is injected into the barrel 1900 from a plasma gun 1915a. Such guns are commonly employed as plasma torches (FIG. 25) and have an annular electrode 1915f coaxial with a central electrode 1915g which defined a chamber 1915h with the outer electrode. The nozzle 1915i is cooled by water circulating through the passage 1915j. A high-temperature arc is sustained in the chamber 1915h and an inert gas may be introduced with or without powder at 1915k to this chamber for conversion into the plasma. The term "plasma" is used herein in the sense considered conventional in the plasma-torch arc and refers to a torch in which the emerging gases are of a temperature such that a substantial portion of the emergent fluid is thermally or electrically ionized. Powder may also be introduced into the gas close to the passage 1915i via a duct 1915m. It will be understood that the plasma injection means can be coaxial with the barrel 1900 in a variant of the modification described. As discussed in connection with FIG. 10, the plasma may, if pulsed, serve as the sole means for controlling the spark discharge and for triggering the device (switch 1909 being permanently closed or eliminated).

WHAT WE CLAIM IS:—

1. A method of forming a coherent body comprising, forming a mass of a powdered material, and compacting said mass by bodily subjecting the mass to the energy of an externally generated shockwave transmitted via a fluid medium thereto and produced by spark discharge in the fluid medium, the energy of said shockwave being sufficient to cause the particles of the powdered material to bond together.

2. The method according to Claim 1 wherein the particles are retained in a die, and a piston-like member is disposed between the spark discharge and the particles to act as a force-transmitting member compacting the particles when the shockwave acts upon the piston-like member.

3. The method according to Claim 1 wherein the mass of particles is disposed between the spark discharge and a substrate and is subjected directly to the shockwave to propel the particles against the substrate with a high-energy-rate force sufficient to cause the particles to bond together and to the substrate and to shape the resulting body either by deforming the substrate as the particles are bonded thereto or by simply bonding the particles thereto.

4. The method according to claim 3 wherein the mass of particles is supported upon a rupturable diaphragm between the spark discharge and the substrate.

5. The method according to Claim 4 wherein the diaphragm is electrically conductive and the spark discharge is generated between an electrode and said diaphragm by applying an electric pulse across the electrode and the diaphragm.

6. The method according to claim 3, 4 or 5 wherein the spark discharge is generated at least in part through the mass of powder.

7. The method according to claim 3 wherein the mass of powder is a cloud of powder suspended in a gas between the spark discharge and the substrate.

8. The method according to claim 7 wherein the particle cloud is formed by thermal erosion of a fusible body along the path of the shockwave between the spark discharge and the substrate.

9. The method according to claim 7 or 8 wherein the cloud of particles is formed by directing a plasma jet against the thermally fusible body.

10. The method according to claim 7 or 8 wherein the fusible body is thermally eroded by an electric arc.

11. The method according to claim 7 wherein the particle cloud is formed by injecting a powder-containing plasma into the path of the shockwave.

12. The method according to claim 3 wherein the impulsive spark discharge is triggered periodically at a rate of at least 0.5 cycle per second.

13. The method according to claim 12 wherein powder masses are introduced into the path of the shockwave in the cadence of triggering the spark discharge.

14. The method according to claim 3 wherein the powder is preheated independently of the spark discharge to facilitate the adhesion of the powder to said substrate.

15. The method according to claim 3, 12 or 14 wherein the powder is heated independently of the spark discharge and prior to the impingement of the powder against the substrate by mixing with the mass of powder, prior to the spark discharge, at least one chemical compound capable of exothermic reaction with the mass initiated at least in part by the discharge.

16. The method according to claim 1, 2 or 3 wherein the energy of the spark discharge is reflected toward the powder mass.

17. The method according to claim 3, 4 or

12 wherein the space between the powdered mass and the substrate is evacuated prior to triggering of the spark discharge.

18. The method according to claim 3, 12 or 14 wherein the particle mass is admixed with a binder and forms an explodable sheath surrounding the spark-discharge gap prior to the generation of the spark discharge.

19. The method according to claim 3, 12 or 14 wherein the spark discharge is formed by initially bridging a pair of electrodes by an electrically destructible conductor and then explosively destroying the conductor by incipient passage therethrough of an electrical pulse to form an electrode gap thereafter sustaining the spark discharge during the remainder of the pulse.

20. The method according to claim 3 wherein successive masses of powdered material are positioned between a spark generator and the substrate to propel the powdered material of these masses successively against the substrate.

21. The method according to claim 20 wherein the masses are disposed along a turntable composed of a frangible material and are rotated into alignment with the spark generator.

22. The method according to claim 20 wherein the masses of powdered material are encapsulated between metal foils to form a band having spaced-apart pockets containing the respective masses the band constituting an electrode, forming part of the spark generator.

23. The method according to claim 22 wherein the foil is composed of aluminum, nickel, cobalt, copper, iron or alloys thereof.

24. The method according to claim 3, 12 or 14 wherein the mass of powder is rendered limitedly coherent by compaction, light sintering or mixture with an adhesive prior to the generation of spark discharge.

25. The method according to claim 3, 12 or 14 wherein the path of the particles is formed by a barrel trained upon the substrate, characterized in that barrel is cooled to a temperature below about 80°C to facilitate deposition of the powder on the substrate.

26. The method according to claim 3, 12 or 14 wherein the distribution of the particles of powder on the surface of the substrate or the coloration of the substrate by the particles is controlled to imprint or otherwise form predetermined patterns on the substrate.

27. An apparatus for carrying out the method of claim 1 comprising an impulse generator having a pair of electrodes in spaced relationship, means for disposing a mass of powder in force-receiving relationship with the generator, and an electric circuit for applying an electric pulse to the electrodes to generate a spark discharge between the electrodes of an intensity sufficient to compact the powder.

28. An apparatus according to claim 27 wherein housing means in the form of a barrel is provided having the impulse generator at a closed end, and an open end trained against a substrate to which the powder is to be applied.

29. The apparatus according to claim 28 wherein a frangible support carrying the mass of powder is disposed in the barrel between the impulse generator and the surface of the substrate adapted to receive a layer of powder.

30. The apparatus according to claim 29 wherein the frangible support is an electrically conductive foil and forms one of the electrodes.

31. The apparatus according to claim 30 wherein the foil constitutes a turntable having a plurality of powder masses thereon and rotatable to align these masses with the generator in succession.

32. The apparatus according to claim 30 wherein the foil is a band formed with a plurality of pockets therealong each containing a respective mass of powder.

33. An apparatus according to claim 30, 31 or 32 wherein said foil is composed of aluminum, nickel, cobalt, copper, iron or alloys thereof.

34. The apparatus according to claim 28 wherein means are provided for introducing a gas-suspended cloud of powder between said generator and a substrate.

35. The apparatus according to claim 34 wherein the means for introducing the cloud of powder includes a fusible body, and means for thermally eroding the fusible body.

36. An apparatus according to claim 35 wherein the means for thermally eroding the fusible body includes means for applying an arc discharge to the fusible body.

37. An apparatus according to claim 35 wherein the means for thermally eroding the fusible body includes a plasma torch trained on said body.

38. An apparatus according to claim 34 wherein the means for introducing the cloud of powder between said generator and the substrate includes a plasma torch forming a plasma stream entraining the particles.

39. An apparatus according to claim 28, claim 29 or claim 34 wherein the generator is triggered periodically and a succession of masses of powder are introduced between the generator and the substrate for the triggering of the generator.

40. An apparatus according to claim 27, 28 or 34 wherein the electrodes are bridged by a fusible conductor destructible upon incipient passage of an electric pulse through the electrodes to form a spark-discharge gap.

41. An apparatus according to claim 27, 28 or 34 wherein means are provided for applying an electromagnetic-force field across the region of the generator for directing the shockwave produced by the discharge.

42. The apparatus according to claim 27, 29 or 34 wherein means are provided for relatively shifting the electrodes and a surface of a substrate in force-receiving relationship in a direction parallel to the surface.

43. The apparatus according to claim 27, 29 and 34 wherein the generator forms part of a chamber vented to the atmosphere through a sound-muffling device.

44. The apparatus according to claim 27 wherein a die provided to retain the powder mass and a piston-like force-transmitting member is interposed between the generator and the mass to compact the latter.

45. An apparatus according to claim 28, 29 or 34, characterized in that means are provided for maintaining the temperature of the barrel below that of 80°C.

46. A method of forming coherent bodies substantially as herein described with reference to the accompanying drawings.

47. Apparatus for carrying out the method of claim 46 substantially as herein described with reference to the accompanying drawings.

For the Applicant,
RAWORTH MOSS & COOK,
Chartered Patent Agents,
38, Sydenham Road,
Croydon, Surrey.
and
75, Victoria Street,
Westminster,
London, S.W.1.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1970.
Published by The Patent Office, 25 Southampton Buildings, London WC2A 1AY. from which copies may be obtained.

1204261 COMPLETE SPECIFICATION

10 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 1

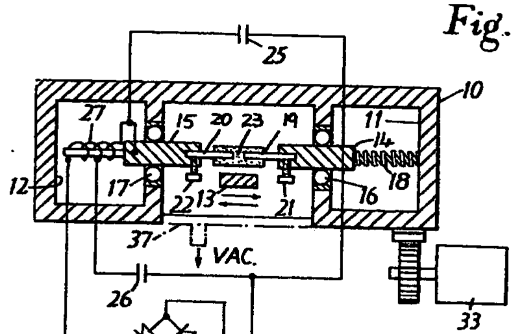


Fig. 1.

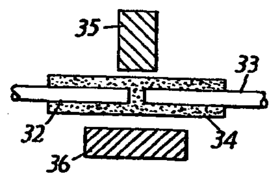


Fig. 2.

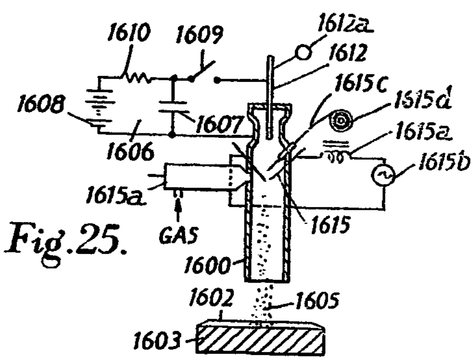


Fig. 25.

1204261 COMPLETE SPECIFICATION
10 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 2

Fig.3.

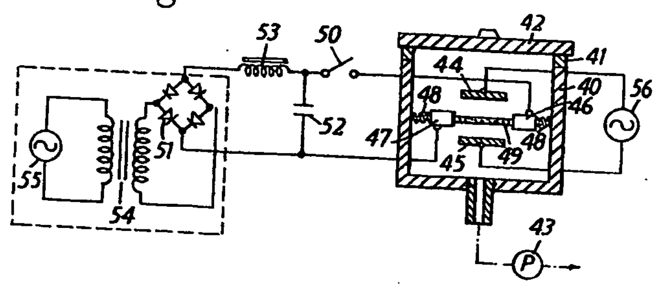


Fig.4.

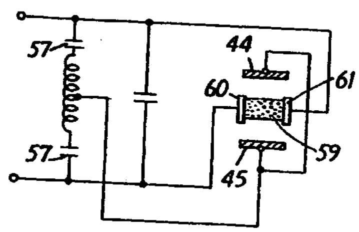
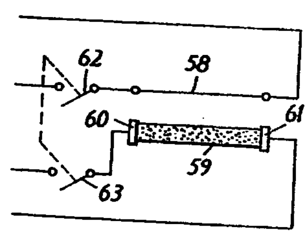


Fig.5.



1204261 COMPLETE SPECIFICATION

10 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 3

Fig. 6.

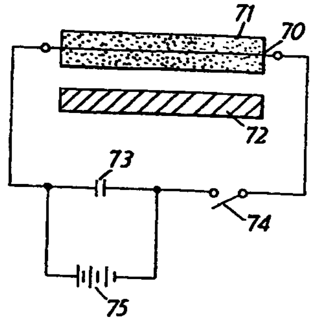


Fig. 7.

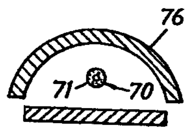


Fig. 9.

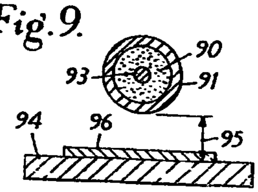
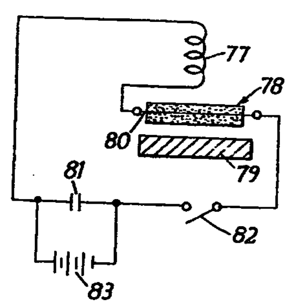


Fig. 8.



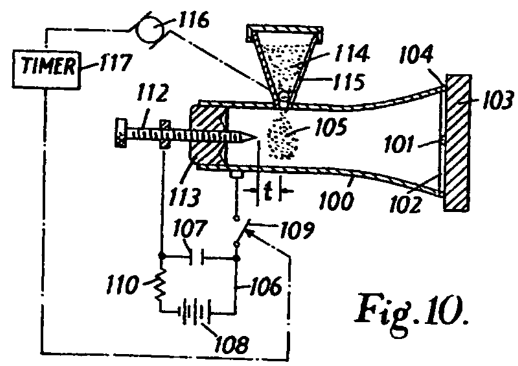
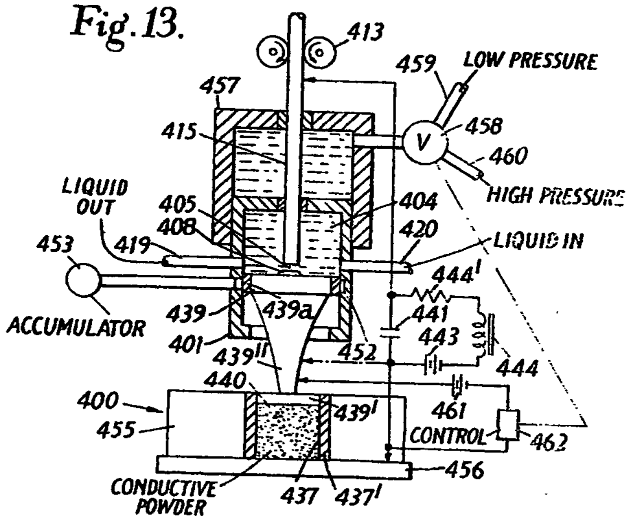

116
TIMER
117
114
104
115
103
112
105
101
113
t
100
102
107
109
110
106
108

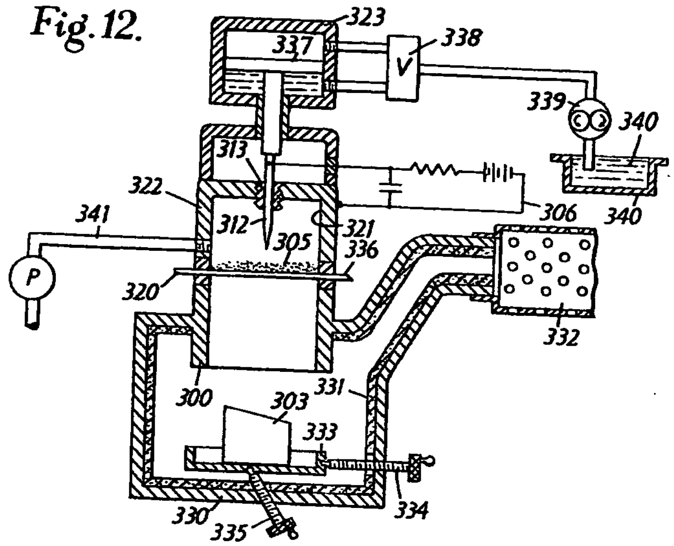
Fig. 10.

Fig. 13.


413
459
LOW PRESSURE
457
458
415
V
460
LIQUID OUT
405
404
HIGH PRESSURE
408
420
453
419
LIQUID IN
444'
ACCUMULATOR
439
439a
441
443
401
452
444
439''
440
400
439'
461
455
CONTROL
462
456
CONDUCTIVE POWDER
437
437'

1204261 COMPLETE SPECIFICATION
10 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 5

Fig. 12.



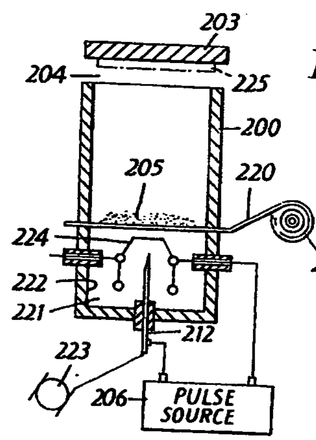


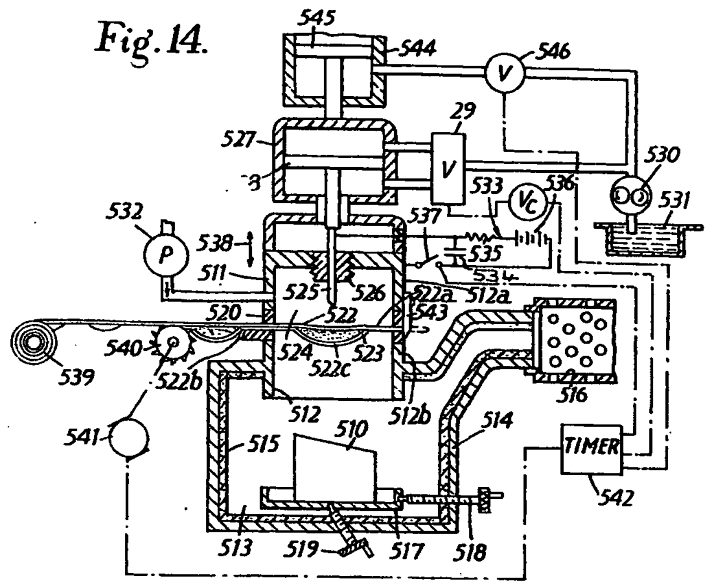
Fig. 11.

1204261 COMPLETE SPECIFICATION

10 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 6

Fig. 14.



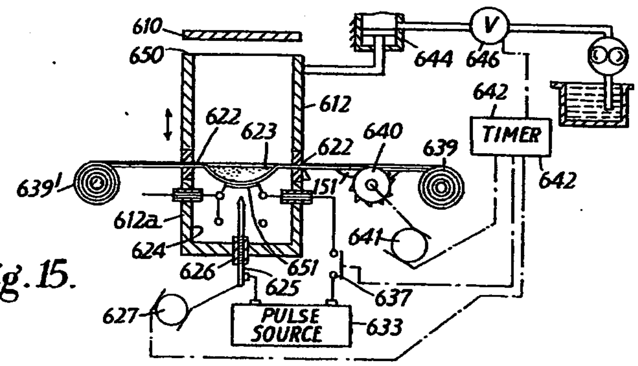


Fig. 15.

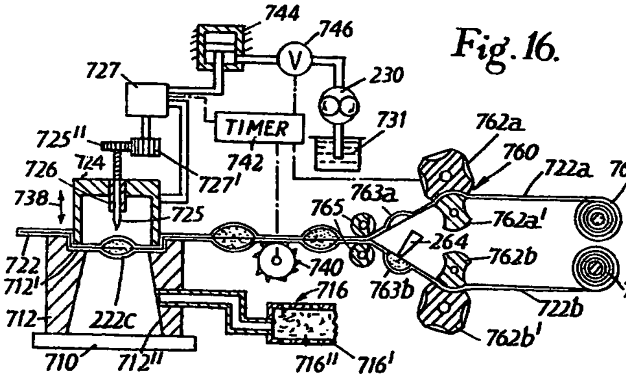
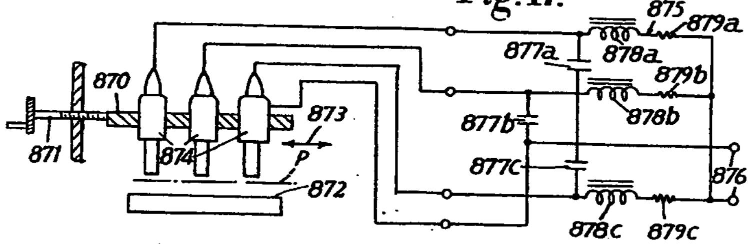


Fig. 16.

Fig. 17.


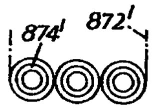


Fig. 18.

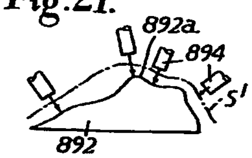
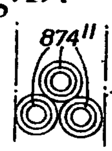
Fig. 21.


Fig. 19.


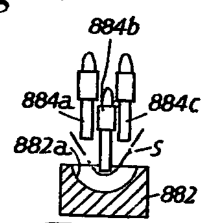


Fig. 20.

Fig. 22.

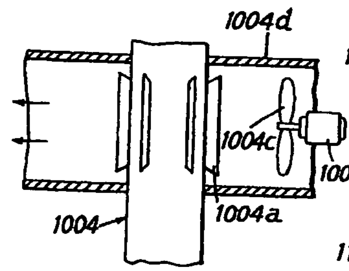


Fig. 23.

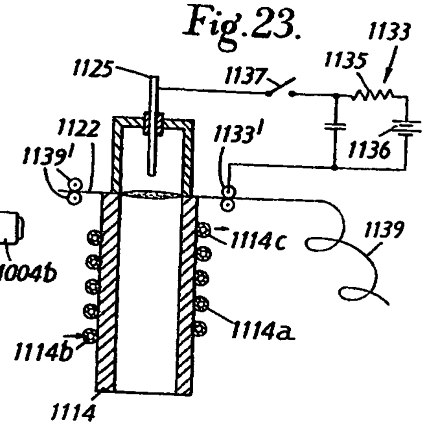


Fig. 24.

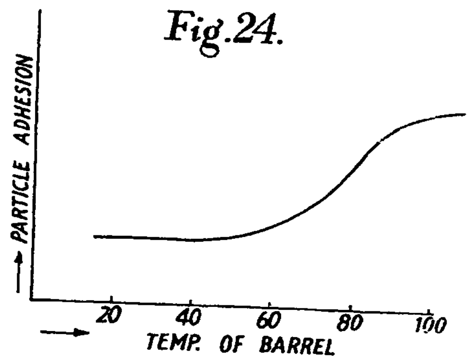


Fig.26.

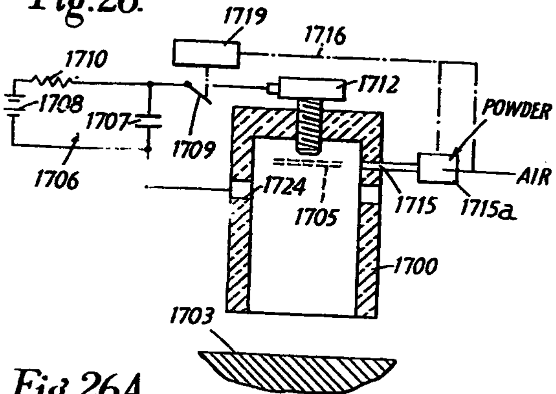


Fig.26A.

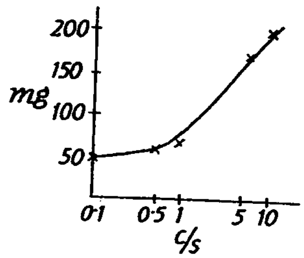


Fig.26B.

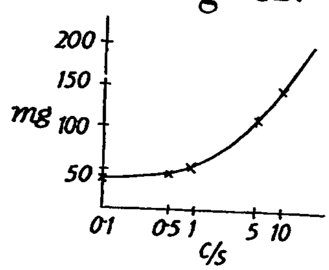


Fig.26C.

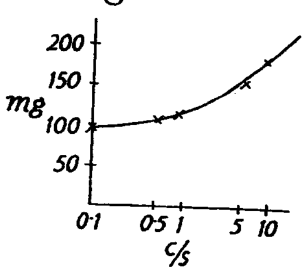


Fig.26D.

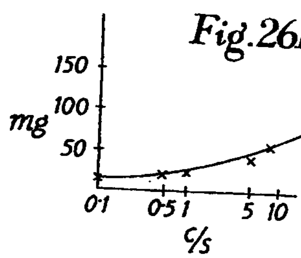


Fig.27.

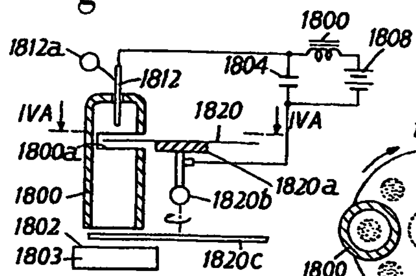


Fig.27A.

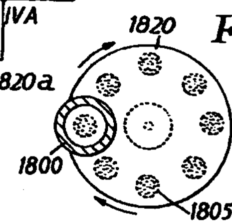


Fig.28.